Sept. 12, 1950

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2,521,763

ELECTRON DISCHARGE DEVICE OF THE ELECTRON VELOCITY MODULATION TYPE

Filed Dec. 19, 1945

2 Sheets-Sheet 1

FIG. 1.

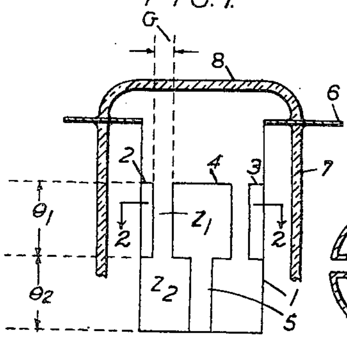


FIG. 2.

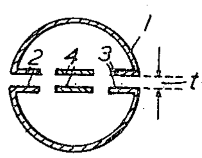


FIG. 3.

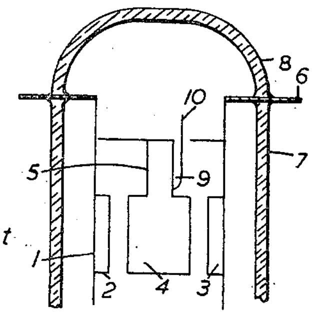


FIG. 4.

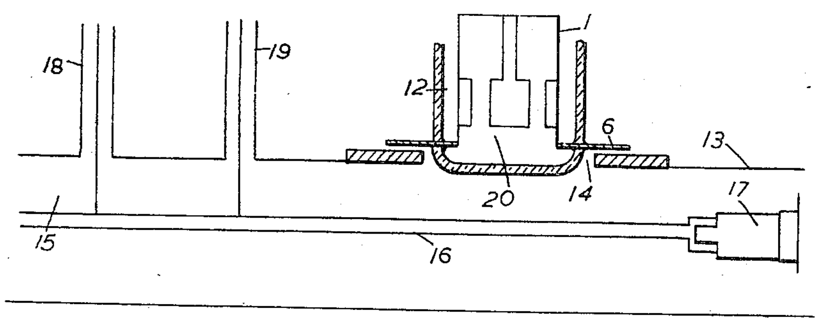
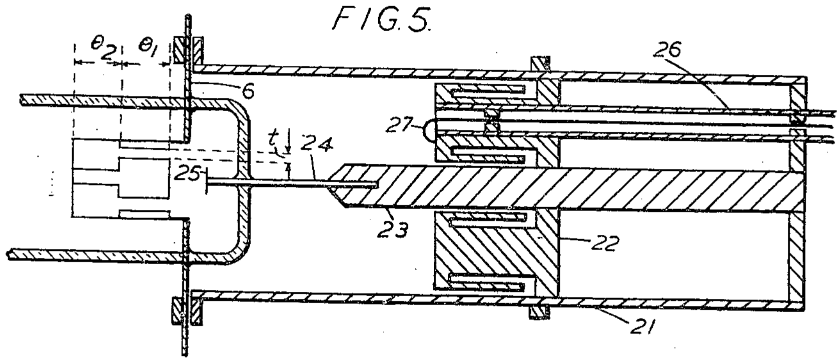


FIG. 5.



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ELECTRON DISCHARGE DEVICE OF THE ELECTRON VELOCITY MODULATION TYPE

Filed Dec. 19, 1945 2 Sheets-Sheet 2

FIG. 6.

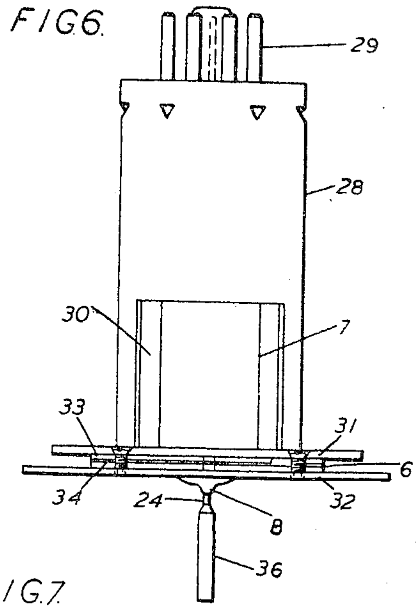


FIG. 7.

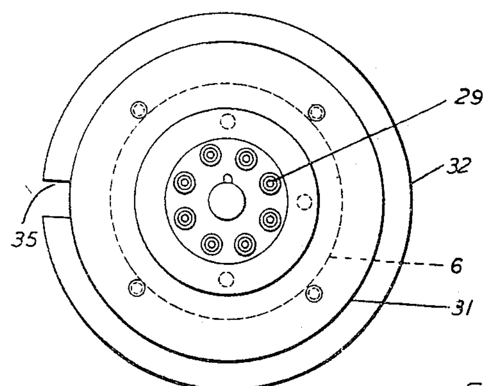
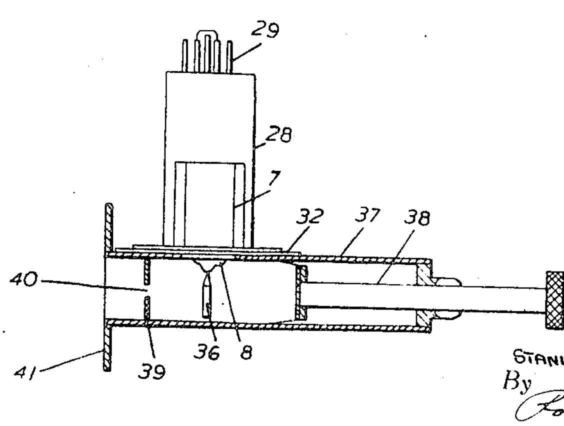


FIG. 8.



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Patented Sept. 12, 1950 2,521,763

UNITED STATES PATENT OFFICE

2,521,763

ELECTRON DISCHARGE DEVICE OF THE ELECTRON VELOCITY MODULATION TYPE

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Application December 19, 1945, Serial No. 636,018
In Great Britain January 21, 1944

Section 1, Public Law 690, August 8, 1946
Patent expires January 21, 1964

16 Claims. (Cl. 315—39)

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The present invention relates to electron discharge devices of the electron velocity modulation type, and is concerned more particularly with tuning means for such devices which employ coaxial line resonators.

The invention provides an electron discharge device comprising a coaxial line resonator enclosed in an insulating envelope and having a central conductor spaced from the walls of the resonator by a pair of gaps, the said conductor having a passage therethrough between the said gaps, and means for projecting a stream of electrons from a cathode across the resonator through the said passage and past the said gaps for exciting oscillations in the said resonator, the said means including means for applying an accelerating voltage to the electrons, and the said gaps being so proportioned that the change of oscillation frequency with change of accelerating voltage is a maximum.

Another feature of the invention consists in an electron discharge device comprising an insulating envelope enclosing a coaxial line resonator having a central conductor spaced from the walls of the resonator by a pair of gaps, the said conductor having a passage therethrough between the said gaps, and electrodes adapted when appropriately polarised for projecting a beam of electrons across the resonator through the said passage and past the said gaps for exciting oscillations in the said resonator, a metal annular disc being sealed through the said envelope to which disc the resonator is rigidly attached.

A further feature is an electron discharge device comprising an insulating envelope enclosing a coaxial line resonator having a central conductor spaced from the walls of the resonator by a pair of gaps, the said conductor having a passage therethrough between the said gaps, and electrodes adapted when appropriately polarised for projecting a beam of electrons across the resonator through the said passage and past the said gaps for exciting oscillations in the said resonator, a lead-out conductor rod being sealed through the said envelope and capacity coupled to the central conductor of the resonator.

The above device is of the type described in British patent specification No. 537,490 and it is well known that in devices of this kind the wavelength generally varies when the accelerating voltage is varied, though the total range of possible variation is usually rather small. For some purposes, attention is directed to the reduction of this variation so that the performance of the device is not greatly affected by fortuitous

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changes in the operating conditions. The principal object of the present invention, however, is to increase the range of variation in order to provide a convenient means for tuning the device.

The possibility of tuning the resonator by adjustment of the accelerating voltage arises from the fact that the electron beam passing across the modulating and working gaps effectively introduces a susceptance load across the resonator, the value of which depends on the velocity of the electrons and on the density of the beam. The fin system used to define the gaps loads the resonator with a constant susceptance which operates in parallel with the variable susceptance introduced by the electron beam and therefore tends to reduce the range of tuning which can be obtained.

A study of the problem has shown that the following conditions should be fulfilled in the design and operation of a device according to the invention:

1. The resonator should be designed so that the resonance frequency changes rapidly with changes in the effective susceptance load produced by the electron beam.

2. The drift tube should be designed so that the electrons occupy a large number of quarter periods of the generated wave in passing through it.

3. The modulating and working gaps should have a high efficiency.

4. The device should be designed to permit the use of a high operating current, while the starting current should be low.

5. The accelerating voltage applied between the cathode and the resonator should be low.

In devices where high stability of operation is required such, for example, as those described in the copending British application No. 17,311/42, the requirements are the reverse of some of those stated above. In the case of the present invention it will be evident that since tuning is by adjustment of the accelerating voltage, it is most desirable that the adjustable source of voltage should be constant in the sense that the voltage for any given setting does not vary.

Certain of the above mentioned conditions are contradictory and it is, therefore, necessary to design the apparatus so that the contradictory effects result in the maximum tuning range. For example, conditions 1 and 3 are in conflict, since a high gap efficiency requires a short gap and thus increases the constant susceptance load. It is, therefore, necessary to adjust the gap width so that the two factors operate to produce the maximum tuning range. Apart from this, condition 1 requires that the coaxial line should be not longer than one quarter of the operating wavelength. The devices according to the present invention accordingly employ resonators of this length. In one preferred form, the resonator comprises a tubular outer conductor welded or otherwise secured at one end to an annular disc sealed through the envelope of the device. The generated waves may be obtained directly from the open end of the resonator, or the energy may be extracted by means of a loop and probe inserted through the closed end.

It may be pointed out in connection with condition 4, that a high operating current implies that the device must be designed to permit a high dissipation, which is assisted by the use of the annular disc sealed through the envelope, and the cathode must allow the desired current to be drawn therefrom without destroying it. It is, therefore, most necessary that the focussing arrangements for the electron beam should be very efficient so that the minimum number of electrons are wasted.

Condition 5 conflicts with this requirement, since the usual electrostatic focussing arrangements are ineffective when the beam current is high and the accelerating voltage is low. For this reason magnetic focussing is almost indispensable for devices designed according to the present invention.

In order to obtain a large beam current, a wide blade-like beam is preferably used.

The invention is illustrated in the accompanying drawings, in which:

Fig. 1 shows diagrammatically with parts in longitudinal section of a device adaptable for electronic tuning;

Fig. 2 shows a transverse section taken along line 2—2 of the diagrammatical portion of Fig. 1;

Fig. 3 shows diagrammatically with parts in section a modification of Fig. 1;

Fig. 4 shows the device of Fig. 1 coupled to a wave guide;

Fig. 5 shows diagrammatically with parts in section a device according to the invention coupled to an external mechanically tunable resonator;

Figs. 6 and 7 show a side view and a bottom view, respectively, of a practical form of a device according to the invention; and

Fig. 8 shows an alternative arrangement similar to Fig. 5.

Referring to Figs. 1 and 2, the resonator 1 of the device comprises a short metal tube closed at the lower end and open at the upper end. Fins 2 and 3 attached to the wall of the resonator and fins 4 attached to the central conductor 5 define a slot for the passage of the electron beam generated by the usual means (not shown). The resonator is attached to an annular disc 6 sealed to the glass envelope 7, the lower part of which is cut away. The upper end of the envelope is closed by a very shallow glass cup 8 also sealed to the disc 6. The waves generated pass out through the open end of the resonator which, however, has been given a diameter below the cut-off diameter, and thus acts to attenuate the waves so that only a small proportion emerges beyond the disc; this arrangement is suitable where only very loose coupling to a load is desired.

Fig. 3 shows a modified arrangement in which the resonator is closed at the upper end, the energy being extracted from the closed end by means of a wire loop 9 placed in a strong part of the field connected to a probe 10 extending through the closed end. The lower end of the resonator may be left open as shown if the diameter is below the cut-off diameter, so that very little energy can escape this way. The arrangement shown in Fig. 3 provides an efficient means of extracting the energy, and is suitable where tight coupling with a load is desired.

The principal consideration in designing a device according to the invention is the choice of the gap-length which gives the maximum change of frequency with change of accelerating voltage. Other dimensions are mainly determined by the mean frequency, beam current, and the like, desired for the device. The conditions governing the gap length are very complicated, and it has been found that the best procedure is to calculate the frequency change obtained for each of a number of different gap lengths and to plot the results on a curve. Such a curve usually shows a maximum for some particular value of the gap length, and this particular value is therefore chosen.

The manner in which these calculations may be performed will now be explained. The resonator can be regarded as consisting of two short transmission lines connected in tandem, the first of which is constituted by the central fin 4 (see Fig. 1), and the fins 2 and 3 in parallel. The characteristic impedance of this line is Z_1 and the electrical length (that is, the total phase change suffered by a wave travelling therethrough) is θ_1. The second transmission line is the lower portion of the resonator between the outer conductor and the central conductor 5. This line is short circuited at its end, and its characteristic impedance and electrical length are denoted as Z_2 and θ_2 respectively.

When designing for a given wavelength, the value of θ_2 has to be determined. It is given by the equation $Z_1=Z_2 \tan \theta_1 . \tan \theta_2$. Z_1 depends on the gap length G and is calculated for each chosen value of G. Z_2 is known from the dimensions of the resonator, and θ_1 from the length of the fins, and so θ_2 is found for each value of G.

Let f be the mean frequency of the device, which is obtained when the accelerating voltage applied between the cathode of the device and the resonator has the mean value V. Let df be the total frequency change obtained when the accelerating voltage is varied between the limits V_1 and V_2, which are the maximum and minimum voltages, respectively, for which the device will oscillate. Let n be the number of quarter periods occupied by the electrons in passing between the fins 4. The value of n will be of the form $4r+1$ where r is an integer or zero, and as already stated, n should be made as large as possible. It can be shown that, approximately, $V_1=n^2V/(n-1)^2$ and $V_2=n^2V/(n+1)^2$.

Calculation shows that

$$\frac{df}{f}=-\frac{Z_1 . d_S}{2Y}\left[1+\frac{\sin 2\theta_1}{2\theta_1}\right]$$

in which

$$dS=\frac{\pi I}{4n^2V}\left[(n-1)^3\beta_1^2+(n+1)^3\beta_2^2\right]-\frac{12}{(n^2-1)\pi R}+\frac{2n^2V}{\pi I R^2}\left[\frac{1}{(n-1)^3\beta_1^2}+\frac{1}{(n+1)^3\beta_2^2}\right]$$

and

$$Y=(\theta_1+Z_2\theta_2/Z_1)\sin^2\theta_1+(\theta_1+Z_1\theta_2/Z_2)\cos^2\theta_1$$

In the expression for dS, I is the electron beam current, R is the resonant impedance of the resonator, and β_1^2 and β_2^2 are the mean square values of the efficiency factor β of the gap at voltages V_1 and V_2, respectively. These factors are calculable by known methods.

The value of θ_1, which should not exceed 1 radian, is usually determined by the voltage distribution along the fins, by the beam current desired, and by the maximum electron emission density allowable for the cathode. This may be of the order of 1 ampere per square centimetre, and if, for example, a beam current of 20 milliamperes is required, the minimum cross section of the beam is thus determined. The thickness of the beam is determined by the spacing t of the fins (see Fig. 2) which should not be too great or the efficiency factor β will be affected. The value of t should probably be of the order of 1% of the wavelength, when the voltage V is of the order of 200 volts, for example. Thus the length of the fins, on which θ_1 depends, is fixed, but its value should preferably not exceed 1 radian. If this should happen, either t should be increased or a lower beam current used.

The resonance frequency of the arrangement is that frequency for which the approximate condition $Z_1=Z_2 \tan \theta_1 . \tan \theta_2$ holds. However, as already mentioned, the smallest value of θ_2 satisfying the condition should be chosen so that the resonator is effectively not more than a quarter wavelength long. Z_2 should be made as large as is permitted by mechanical consideration.

After having found the best value of G from the curve in the manner explained, the corresponding starting current for the device should be checked in order to be sure that it is not greater than about one third of the beam current it is proposed to use, otherwise the equations given above do not hold with sufficient accuracy. If the starting current should come out too high the process of determining G using a different value of t should be repeated.

In order to decrease the capacity across the gaps, the thickness of the fin material should be made as small as mechanical considerations allow.

In order to give an example, dimensions are quoted for a particular case of a device designed in the manner explained in order to obtain the maximum value of df/f, magnetic focussing being used.

Wavelength of operation	10 cms.
Electron transit time in drift tube	9 quarter periods
Accelerating voltage V	About 250 volts
Current density of beam	1 amp. per sq. cm.
Beam current	20 milliamps
Tuning range	± 15 megacycles per sec.
Length of fins	1 cm.
Length of central conductor	0.56 cm.
Width G of gaps	0.05 cm.
Thickness t of beam	0.05 cm.
Internal diameter of resonator	0.8 cm.

The diameter of the central conductor was chosen to make the characteristic impedance of Z_2 about 90 ohms, and the thickness of the material used for constructing the resonator and fins was about 0.4 mm. It will be understood, of course, that this is only one example of a device designed according to the invention; and if another device is required for some other wavelength, other dimensions would be used.

It will be seen from the above table of values that the value of V is only 250 volts. The accelerating voltage used in devices of this kind not intended for electronic tuning is commonly of the order of 1500 volts; thus it will be understood that in condition 5 above, a low accelerating voltage means something like a quarter of the usual accelerating voltage, or less.

The device designed according to the invention may be coupled, for example, to a wave guide or coaxial line by assembling it through a hole in the wall of the guide so that the coaxial resonator forms effectively a side tube, the annular disc 6 being used effectively to complete the wall of the wave guide. Such a guide may contain mixing arrangements for modulating or demodulating a signal wave. In such a case, a device provided with electronic tuning is particularly desirable to serve as the local oscillator, preferably in the form described with reference to Fig. 1. The oscillator is directly coupled to the wave guide without intermediate transmission line and no mechanical tuning arrangements are required. The apparatus thus becomes extremely simple. This can be seen from Fig. 4. The device 13 as described with reference to Fig. 1 is coupled directly to the coaxial line 13 through a suitable aperture 14, the disc 6 completing the wall of the coaxial line. Signals are entering at the end 15 of the coaxial line, the conductor 16 of which terminates in a demodulating means 17 such as a crystal. The usual matching stubs 18 and 19 are provided.

The desired loose coupling results from the short length of tube 20 at the mouth of the resonator 1 as already explained, and this prevents any serious loss of the signal or intermediate frequency waves in the resonator. The necessary tuning of the device 12 to suit the incoming signals is very simply achieved by adjusting the accelerating voltage as explained above.

As shown in Fig. 5, the device according to the invention may, if desired, be provided with mechanical tuning to supplement the electronic tuning already described. An external coaxial resonator 21 with an adjustable annular tuning piston 22, of known form, may be coupled to the annular disc 6 in order to form effectively an axial continuation of the internal coaxial resonator. Any other suitable type of coaxial piston may be used. This figure shows another method according to the invention for extracting the energy from the device. The central conductor 23 of the external resonator is capacity coupled to the central conductor 5 of the internal resonator 1 by means of a suitable rod conductor 24 which is sealed through the cup portion 8 of the envelope of the device, and which terminates in a small metal plate 25 placed near the fins 4 of the central conductor 5 inside the envelope. Energy may be extracted from the resonator 21 by means of a coaxial transmission line 26 passing through the piston 22 and terminating in a loop 27 inside the external resonator. In a particular case, the disc 25 was about 4¾ mm. in diameter and was spaced a distance of about 0.6 mm. from the fins 4.

It is found that the generated wavelength can usually have two different values for each setting of the piston, except over a certain intermediate portion of the range of the piston, when only one value is possible. This intermediate range should preferably be used, and its extent is determined by the value of the capacity used to couple the two central conductors together, which may be suitably chosen.

The range of electronic tuning is decreased and the useful range of the mechanical tuning is increased when the above-mentioned coupling capacity is increased, and vice versa. The two tuning ranges are, therefore, complementary.

It will be understood that an arrangement like the rod 24 and plate 25 may be used to couple the resonator 1 to any kind of outside load, and are not necessarily confined to the particular case shown in Fig. 5.

Figs. 6 and 7 show a practical form of construction for a device according to the invention. The device is mounted inside a protective cylindrical metal tube 28 having at one end an insulating base carrying terminals 29 for the electrodes of the device, and having at the other end two diametrically opposite apertures 30 (only one of which is designated) through which the envelope portion 7 of the device can be seen. The metal tube 28 is provided with a flange 31 to which is screwed an annular disc 32. The copper disc 6 is sandwiched between the elements 31 and 32, with insulating mica washers 33 and 34 on either side. The apertures 30 are provided to enable the poles of a focussing magnet (not shown) to be brought close to the surface of the envelope portion 7. A slot 35 in the disc 32 is provided to accommodate a pin or the like in the apparatus (not shown) with which the device is to be used, in order to obtain the proper orientation of the electron stream with respect to the magnetic field.

A cylindrical sleeve 36 is attached to the conductor rod 24 sealed through the envelope portion 8 of the device. This sleeve forms a suitable antenna for the arrangement to be described with reference to Fig. 8, but is not required when the device is used in the arrangement of Fig. 5.

It will be understood that the disc 6 with the resonator 1 attached thereto will be insulated from the metal case 28 by means of the mica washers 33 and 34, but these washers form a bypass condenser for the high frequency currents so that the disc and resonator are effectively at the same high frequency potential as the case This arrangement allows a suitable operating potential to be applied to the resonator 1 while the case 28 may be maintained at earth potential.

Fig. 8 shows an alternative form of the external mechanical tuning arrangement for the device of the invention which differs from Fig. 5 in a number of details. The device is shown enclosed in a metal case 28 in the manner described with reference to Figs. 6 and 7. The envelope portion 8 carrying the conductor rod and antenna 36 projects through a circular hole in the side of a hollow resonator 37 of rectangular section, the continuity of the resonator wall being maintained by the disc 32 which closes the hole.

The resonator 37 is closed at the right hand end by an adjustable piston 38, and at the left hand end by a diaphragm 39 having an aperture 40. A flange 41 is provided for coupling the resonator to a wave guide, for example.

The dimensions of the antenna 36 and of the aperture 40 will depend upon the wavelength range for which the device is to be used and will most easily be found by experiment.

What is claimed is:

1. An electron discharge device comprising a coaxial line type resonator having central and outer conductors provided with a set of apertures extending along a line passing through said conductors, beam producing means external of said resonator and aligned with said apertures, an envelope enclosing said resonator and said beam producing means, an apertured disc secured to one end of said resonator and sealed through the walls of said envelope, said resonator being open at the end to which said disc is secured, and a lead-out conductor rod sealed through said envelope and capacity coupled to said central conductor.

2. A discharge device as set forth in claim 1 in which a metal plate is attached to that end of said rod which is inside the envelope, the said plate being placed close to the said central conductor for the purpose of forming a condenser therewith.

3. A discharge device as set forth in claim 1 further comprising a second coaxial resonator having its outer conductor secured to said disc and its inner conductor electrically connected to said lead out conductor rod.

4. A discharge device as set forth in claim 3 in which said second coaxial resonator comprises mechanical means for tuning said second resonator whereby the resonator frequency of said first resonator is adjusted.

5. An electron discharge device comprising a coaxial line type resonator, having central and outer conductors provided with a set of apertures extending along a line passing through said conductors, beam producing means external of said resonator and aligned with said apertures, an envelope enclosing said resonator and said beam producing means, an apertured disc secured to one of said resonators and sealed to walls of said envelope, said disc providing means for coupling said resonator to an external circuit, an accelerating electrode arranged about the beam path, said central and outer conductors having fins extended about said apertures and parallel to the line of said apertures to define gaps between the beam path and the interior of said resonator.

6. A discharge device as set forth in claim 5 in which said resonator is open at the end where said disc is secured whereby waves generated in said resonator pass out through that end.

7. A discharge device as set forth in claim 6 in which said disc further comprises means for securing said discharge device about the aperture in the external wall of a wave guide.

8. A discharge device as set forth in claim 5 further comprising means closing the end of said resonator at which said disc is secured and a loop sealed through said envelope and inserted through an aperture in said closing means and located in a region of said resonator adapted to have a high field intensity for transferring energy from said resonator to an external surface coupled to said resonator.

9. An electron discharge device comprising a coaxial line type resonator having central and outer conductors provided with a set of apertures extending along the line passing through said conductors, beam producing means external of said resonator and aligned with said apertures, an envelope enclosing said resonator and said beam producing means, an apertured disc secured to one end of said resonator and sealed through the walls of said envelope, said disc providing means for coupling said resonator to an external circuit, and accelerating electrode arranged about the beam path, said central and outer conductors having fins extending about said apertures and parallel to the line of said aper-

tures to define gaps between the beam path and the interior of said resonator, said resonator being open at the end to which said disc is secured, and a lead out conductor rod sealed through said envelope and capacitively coupled to the central conductor of said resonator.

10. Electron discharge device as set forth in claim 9 in which a metal plate is attached to that end of the said rod which is inside the envelope, the said plate being placed close to said central conductor for the purpose of forming a condenser therewith.

11. An electron discharge device as set forth in claim 9 further comprising a second coaxial resonator secured to said disc, the inner conductor of said second resonator being electrically connected to said lead out conductor rod.

12. An electron discharge device as set forth in claim 11 in which said second coaxial resonator comprises mechanical means for tuning said second resonator whereby the resonant frequency of said first resonator is adjusted.

13. An electron discharge device as set forth in claim 1 further comprising an antenna electrically connected to said lead out conductor rod.

14. An electron discharge device as set forth in claim 1 further comprising a wave guide secured to said disc and an antenna arranged inside said wave guide and electrically connected to said lead out conductor rod.

15. An electron discharge device comprising a coaxial line type resonator having central and outer conductors provided with a set of apertures

extending along a line passing through said conductors, beam producing means external of said resonator and aligned with said apertures, an envelope enclosing said resonator and said beam producing means, an apertured disc secured to one end of said resonator and sealed through the walls of said envelope, a shield arranged about said envelope, said shield having diametrically opposed openings adjacent one end thereof for the poles of a focusing magnet, a flange on said shield, and means securing said flange to said disc.

16. A discharge device as set forth in claim 15 in which said shield is provided with apertures adapted to enable the poles of a focusing magnet to be brought close to the electron beam path.

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